IS 8504-3 (1994): Guide for determination of thermal endurance properties of electrical insulating materials, Part 3: Statistical methods [ETD 2: Solid Electrical Insulating Materials and Insulation Systems]

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भारतीय मानक

(Reaffirmed 2004)

विद्युत रोधन के ताप सहायता गुण धर्मों को ज्ञात करने की मार्गदर्शिका

भाग 3 संख्याकीय पद्धतियाँ

Indian Standard

GUIDE FOR DETERMINATION OF THERMAL ENDURANCE PROPERTIES OF ELECTRICAL INSULATING MATERIALS

PART 3 STATISTICAL METHODS

UDC 621·315·61 : 620·199

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February 1994

Price Group 6

Solid Electrical Insulating Materials Sectional Committee, ETD 02

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Solid Electrical Insulating Materials Sectional Committee had been approved by the Electrotechnical Division Council.

This standard is part of the following series of standards:

Part 1 General guidelines for ageing procedures and evaluation of test results

Part 2 List of materials and available tests

Part 3 Statistical methods

Part 4 Instructions for calculating thermal endurance profile

In the formulation of this standard, assistance has been derived from IEC 216-3 Guide for the determination of thermal endurance properties of electrical insulating materials : Part 3 Statistical methods issued by the International Electrotechnical Commission.

Indian Standard

GUIDE FOR DETERMINATION OF THERMAL ENDURANCE PROPERTIES OF ELECTRICAL INSULATING MATERIALS

PART 3 STATISTICAL METHODS

1 SCOPE

This standard gives statistical methods for the determination of the thermal endurance graph and the thermal endurance profile of electrical insulating materials, as well as the temperature index.

2 OBJECT

The procedures described in this standard apply to the determination of the thermal endurance properties of electrical insulating materials.

The thermal endurance graph of an electrical insulating material is a graph showing the dependence on temperature of a selected property of the material, based on specified tests during or after exposure to different temperatures.

The temperature index consists of the number corresponding to the temperature in degree Celsius derived from the thermal endurance relationship at one given time, normally 20 000 h, unless otherwise specified.

The thermal endurance profile consists of two numbers corresponding to the temperatures in degrees Celsius derived from the thermal endurance graph at 20 000 h and 5 000 h, followed by a number corresponding to the lower 95% confidence limit on the temperature at 5 000 h.

The determination of the confidence limit necessitates a statistical treatment of the results of the thermal endurance tests. Formulae for this statistical treatment are given in the following.

The experimental data which are to be treated statistically in order to obtain the thermal endurance properties are the times to failure, for example the times to reach a specified end point as a result of a thermal ageing treatment of a number of specimens at different ageing temperatures.

The statistical treatment of the test data given below is based on the assumption that a linear relationship exists between the logarithm of the time to failure and the reciprocal of the thermodynamic (absolute) temperature, which, for example, is the case when the degradation is due to a first order chemical reaction and thus obeys Arrhenius' law. Since changes in the ageing mechanism with temperature may invalidate this assumption outside the range covered by the exposure temperatures, even if not detectable within this range, the lowest exposure temperature should be chosen to result in an average time to failure of at least 5 000 h, and the extrapolation necessary to establish the thermal endurance profile or the temperature index should be not more than 25°C.

In cases where the measured values clearly indicate that such a linear relationship does not exist no extrapolation should be made. Curves of the property tested versus time at the different exposure temperatures may give valuable information in such cases, but a temperature index may only be derived after tests with an exposure temperature giving an average time to failure of at least 20 000 h.

The number of specimens exposed at each temperature has a great influence on the accuracy of the test results. If the probable spread in the test results can be anticipated, it is possible to calculate the number of specimens necessary to obtain an acceptable confidence in the results, otherwise guidance may be obtained from preliminary tests.

If suspicion arises that isolated extreme test results do not belong to the population, these may be sorted out as outliers by statistical methods, but only after careful examination of the circumstances of the test, and their value should be noted in the report. In such cases the number of test results at the various exposure temperatures will usually be different.

The methods for treating the data depend to some degree on the experimental procedure. The following cases should be distinguished:

a. Ageing procedure.
   - a.1 Continuous.
   - a 2 Cyclic.

b. Evaluation of the state of the specimens.
   - b.1 Non-destructive measurement of property/properties.
     - b.1.1 Continuous monitoring.
     - b.1.2 Periodic measurements.

b.2 Periodic application of a specified test stress (proof tests).

b.3 Destructive determination of a property.

Method b.1 may be applied in combination with either Procedure a.1 (continuous ageing), or Procedure a.2 (cyclic ageing) in which case the purpose of the cycling may be, for example, to expose the test specimens to defined thermal shocks during ageing. If the measurements are recorded continuously or by frequent scanning (b.1.1), the times to failure are obtained directly by examination of the recorded values, and if periodic measurements are made (b.1.2) they are interpolated on graphs of property versus time (*see* **4.1**). In both cases the time to failure is determined for each individual specimen as a continuous variable and the rate of change of the property appears from the measurements, which is not the case with Methods b.2 and b.3. The evaluation of the results is described in **4**.

Method b.2 is most frequently applied in connection with Procedure a.2 (cyclic ageing). The proof test determines whether the tested property of a specimen is still within the limit of the proof stress (end-point criterion) or not. If the proof test is applied, for example at the end of each ageing cycle, the time to failure is defined as the midpoint of a cycle, and is thus a discontinuous variable (*see* **4.1**). Since the variation during time of the property is not revealed by the test, this method is not as informative as Method b.1. The statistical procedure for obtaining the thermal endurance profile is analogous to the procedure used in case b.1 and is described in **4**.

Method b.3 may be applied to either Procedure a.1 or a.2. A predetermined number of specimens are examined and then discarded, at each time of measurement. Since the values of the property at the different measuring times are determined on different specimens, this method is more sensitive to variations between specimens than the above methods. It is not possible to obtain a time to failure for the individual specimens, but the results indicate the general trend of property versus time and an average time to failure at each ageing temperature. The statistical procedures for obtaining the thermal endurance profile in this case are discussed in **5**.

A flow diagram, showing the main steps in the statistical procedure and the decisions to be taken is given in Annex B.

3 STATISTICAL PROCEDURES

3.1 The statistical procedures involved comprise the following steps:

1) Determination of the times to failure.
2) Calculation of the coefficients a and b of the linear equation of regression $y = a + bx$ of the logarithm of time to failure ($y = \lg t$) on the reciprocal value of the thermodynamic temperature ($x = 1/\Theta$).
3) Drawing the thermal endurance graph.
4) Determination of the temperature index (when applicable).
5) Testing the equality of the variances of the logarithm of the times to failure at the different ageing temperatures.
6) Test for linearity of the regression equation.

   NOTE — It is emphasized that this test applies to the range of measured points only, and that confidence limits calculated for extrapolated points are based exclusively on the assumption of linearity mentioned below (*see* **3.2**, Item 4).

7) Determination of the lower unilateral 95% confidence limit on the logarithmic mean time to failure on the regression line.
8) Calculation of the values of temperature θ°C corresponding to times to failure of 5 000 h and 20 000 h according to the regression equation.
9) Check the coefficient of variation of the logarithm of time to failure according to the regression equation at 5 000 h.
10) Calculation of the lower unilateral 95% confidence limit on the temperature corresponding to a time to failure of 5 000 h on the regression line.

3.2 Assumptions

The assumptions underlying the statistical procedures are as follows:

1) The observed values of time to failure are *stochastically independent*. The specimens used for the ageing test constitute a random sample from the population investigated, and have been treated uniformly.
2) The dependent variable y (logarithm of time to failure) is *normally distributed* at each value of the independent variable x (reciprocal value of thermodynamic temperature).
3) *The variance* σ^2 of y is the *same* at all values of x.
4) The dependent variable y is a *linear* function of the independent variable x, at least over a range including all test points and all extrapolated points.
5) The *errors* in x are *negligible*, so that x has the same exactly known value for all specimens aged at the same temperature.

4 NON-DESTRUCTIVE MEASUREMENTS AND PROOF TESTS

In cases where the end-point criterion is revealed by non-destructive measurements of one or more properties (**2**, Item b.1) or by applying a specified proof test (**2**, Item b.2) the procedure described in this clause applies. The procedure to be followed in the case of destructive determination of a property (**2**, Item b.3) is given in **5**.

4.1 Times to Failure

A total of N specimens are exposed at k different temperatures θ_i°C, where i = 1...k. The number of specimens exposed at θ_i °C is designated n_i ($N = \Sigma n_i$). Usually experiments are planned with the same number, n, of specimens exposed at all temperatures ($N = kn$), but it is also possible to carry out the calculation in cases where the n_i's are different.

For each specimen a time to failure is obtained as described below. The individual timest o failure are designated t_{ij}, where the first index, i. indicates the relevant exposure temperature (θ_i°C), and the second index, j, the number allocated to the specimen within the series of n_i specimens exposed at that temperature, i e., j = 1 ... n_i

4.1.1 *Continuous Monitoring (b.1 1)*

By continuous monitoring the measured property values are recorded continuously or by frequent scanning of the specimens during exposure. Examination of the recorded values will directly reveal the time when the end-point criterion was exceeded for each specimen, that is, the individual time to failure t_{ij}.

4.1.2 *Periodic Measurements (b.1.2)*

If the specimens exposed at one temperature are measured at predetermined times t_1, t_2 , the individual time to failure for each specimen, t_{ij}, may be determined from a graph of property versus time.

4.1.3 *Proof Tests (b.2)*

If a proof stress is applied at predetermined times, the outcome of the test is a time t_l when failure was first observed, and the immediately preceding test time t_{l-1} when failure was last not observed.

The individual time to failure is taken as the mean of these two values, i.e.,

$$t_{ij} = \frac{t_l + t_{l-1}}{2}\ .$$

4.2 The Regression Equation

For each value of the temperature θ_i, calculate the reciprocal value of the thermodynamic temperature $\Theta_i = \theta_i + 273$,

$$x_i = \frac{1}{\Theta_i}.$$

the logarithm of the times to failure t_{ij},

$$y_{ij} = \lg t_{ij}$$

and the mean values of y_{ij},

$$\bar{y}_i = \frac{\Sigma y_{ij}}{n_i}.$$

The coefficients of the regression equation

$$y = a + bx$$

are determined from the equations

$$a = \bar{y} - b\bar{x}$$

$$b = \frac{N\Sigma\ (\ x_i\ \Sigma y_{ij}\ ) - (\ \Sigma n_i\ x_i\ )\ (\ \Sigma\Sigma y_{ij}\ )}{N\ \Sigma n_i\ x_i^2 - (\ \Sigma n_i\ x_i\ )^2}.$$

where

$$\bar{x} = \frac{\Sigma n_i\ x_i}{\Sigma n_i}$$

and

$$\bar{y} = \frac{\Sigma\Sigma y_{ij}}{\Sigma n_i} = \frac{\Sigma n_i\ \bar{y}_i}{\Sigma \bar{y}_i}.$$

4.3 The Thermal Endurance Graph

When the regression line has been established, it is drawn on the thermal endurance graph, i.e., a graph with $y = \lg t$ as ordinate, and $x = 1/\Theta$ as abscissa. Usually x is plotted as increasing from the right to the left, and the corresponding values of θ in °C are marked on the axis (*see* Fig. 1). Special graph paper is obtainable for this purpose.

The individual values $l_g\ y_{ij} = t_{ij}$, and the mean values $\bar{y}_i = \lg t_i$ where t_i denotes the logarithmic mean values of time to failure, are plotted on the graph at the corresponding values of

$$x_i = \frac{1}{\theta_i + 273}.$$

4.4 The Temperature Index

When applicable, the temperature index, TI, is determined from the thermal endurance graph **4.3**, as the temperature θ (in °C) on the regression line corresponding to a specified time T, normally 20 000 h.

The TI should only be derived if the positions of the experimental points relative to the regression line justify the assumption of a linear relationship.

4.5 Test for Equality of Variances

For each value of i, one calculates the variances

$$s_{1i}^2 = \frac{n_i\ \Sigma y_{ij}^2 - (\ \Sigma y_{ij}\ )^2}{n_i f_i}$$

with $f_1 = n_i - 1$ degrees of freedom, and their weighted mean

$$s_1^2 = \frac{\Sigma f_i\ s_{1i}^2}{\Sigma f_1}$$

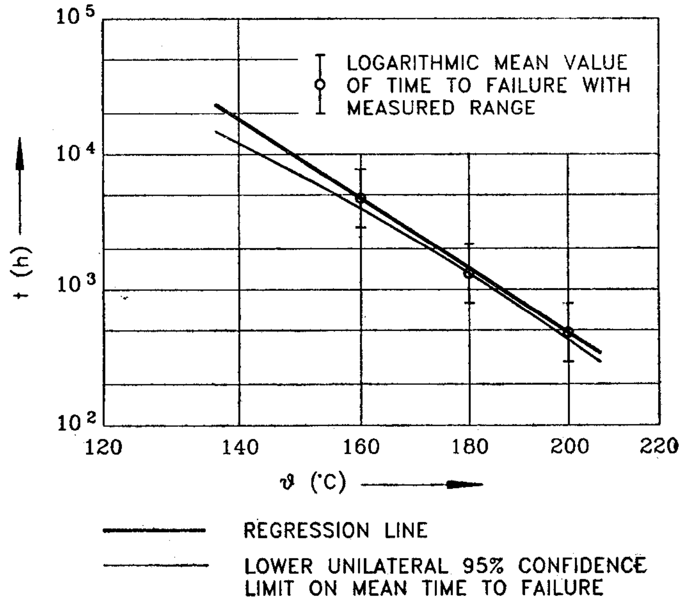

FIG. 1 THERMAL ENDURANCE GRAPH

with

$$f_1 = \Sigma f_i \quad \text{degrees of freedom.}$$

The equality of the k variances s_{1i}^2 is tested by Bartlett's test on significance level $\alpha = 0{\cdot}05$ by comparing the test variable

$$\chi^2 = \frac{2{\cdot}3\,[f_1 \lg s_1^2 - \Sigma\,(f_i \lg s_{1i}^2)\,]}{c}$$

where

$$c = 1 + \frac{\left(\Sigma \frac{1}{f_i}\right) - \frac{1}{f_1}}{3\,(k-1)}$$

$$f_1 = \Sigma f_i$$

with the tabulated value χ^2 (0·95, $k - 1$), where $k - 1$ is the number of degrees of freedom of χ^2, (*see* Annex A).

If χ^2 is greater than the tabulated value, the differences in s_{1i}^2 are considered significant, and the value of χ^2 shall be given in the test report. The weighted mean s_1^2 is used as a pooled estimate of the variance within the k sets of measurements with f_1 degrees of freedom.

4.6 Test for Linearity

From the regression equation one calculates the estimated mean values of y according to the regression line

$$Y_i = a + bx_i$$

corresponding to the k values of x_i, and hence the variance

$$s_2^2 = \frac{\Sigma n_i\,(\bar{y}_i - Y_i)^2}{f_2}$$

$$= \frac{(\Sigma n_i \bar{y}_i^2 - N\bar{y}^2) - b\,(\Sigma n_i x_i \bar{y}_i - N\bar{x}\bar{y})}{f_2}$$

with

$$f_2 = k \times 2 \text{ degrees of freedom.}$$

The pooled estimate s_1^2 of the variance within the k sets of measurements is compared with the variance s_2^2 about the regression line by Fisher's test on significance level $\alpha = 0{\cdot}05$.

The test variable $F = \frac{s_2^2}{s_1^2}$ is compared with the tabulated value of F ($0{\cdot}95, f_n, f_d$), *see* Annex A

Here f_n is the number of degrees of freedom of the numerator of F, and f_d of the denominator, that is, f_n is equal to f_2 calculated above, and f_d equal to f_2 is shown in **4.5**.

If F is greater than the tabulated value, the deviation from the straight line is considered significant and the value of F shall be given in the test report.

A pooled estimate of the variance is calculated as

$$s^2 = \frac{(N-k)\,s_1^2 + (k-2)\,s_2^2}{N-2}$$

with

$$f = N - 2 \text{ degrees of freedom.}$$

4.7 Confidence Limit on Time in the Graph

The lower unilateral 95% confidence limit on the true value of y at a given value X is

$$Y_c = Y - t\,s_y$$

where

$$Y = a + bX$$

$$s_y^2 = s^2 \left[\frac{1}{N} + \frac{(X - \bar{x})^2 N}{N \Sigma n_i x_i^2 - (\Sigma n_i x_i)^2} \right]$$

and t is the tabulated value of Student's t with $f = N \times 2$ degrees of freedom corresponding to 95% confidence level, t (0·95, f), (*see* Annex A).

Y_c is calculated for several connected values of Y and X of the regression equation, distributed over the range of interest, and a curve through the points (X, Y_c) drawn on the graph.

4.8 Temperatures Corresponding to 5 kh and 20 kh to Failure

From the regression equation

$$y = a + bx$$

one calculates the values X_5 and X_{20} corresponding to the values

$$Y_5 = \lg 5\,000 = 3{\cdot}70,$$

and

$$Y_{20} = \lg 20\,000 = 4{\cdot}30,$$

and hence the corresponding temperatures in degrees Celsius

$$\theta_5 = \frac{1}{X_5} - 273$$

and

$$\theta_{20} = \frac{1}{X_{20}} - 273$$

4.9 Coefficient of Variation

The variance of Y_5 as determined from the regression equation corresponding to the temperature θ_5 is calculated as

$$s_y^2 = s^2 \left[\frac{1}{N} + \frac{(X_5 - \bar{x})^2 N}{N \Sigma n_i x_i^2 - (\Sigma n_i x_i)^2} \right]$$

and hence the coefficient variation

$$CV = \frac{s_y}{\lg 5\,000} = \frac{s_y}{3{\cdot}7}$$

If the coefficient of variation $CV \leqslant 1{\cdot}5$ %, the thermal endurance profile is determined as per **4.11**; if not, only the thermal endurance graph **4.3** and when applicable, the temperature index **4.4** are reported.

4.10 Confidence Limit on Θ_5

The lower unilateral 95% confidence limit θ_c on the temperature corresponding to 5 000 h to failure is calculated from

$$X_c = \bar{x} + \frac{Y_5 - \bar{y}}{b_r} + \frac{t\, s_r}{b_r}$$

where

$$b_r = b - \frac{t^2 s^2}{b\, \Sigma n_i (x_i - \bar{x})^2}$$

$$s_r^2 = s^2 \left[\frac{b_r}{Nb} + \frac{(X_5 - \bar{x})^2 N}{N \Sigma n_i x_i^2 - (\Sigma n_i x_i)^2} \right]$$

and t is the tabulated value of Student's t with $f = N - 2$ degrees of freedom corresponding to 95% confidence level, t (0·95, f), (*see* Annex A).

$$\theta_c = \frac{1}{X_c} - 273$$

4.11 The Thermal Endurance Profile

The thermal endurance profile (TEP) is determined as the numbers corresponding to the temperatures yielding an estimated logarithmic mean time to failure of 20 kh and 5 kh, θ_{20} and θ_5 (**4.8**) followed by Θ_c (**4.10**).

TEP Θ_{20}/Θ_5 (Θ_c)

5 DESTRUCTIVE MEASUREMENTS

When destructive measurement of a property is used to determine the end point (2, Item b.3), the number of specimens exposed at each temperature shall be at least equal to the product of the number of specimens measured at the end of each time interval, and the number of times t_1, t_2..., at which the measurements are carried out.

If, for example, it is planned to measure ten specimens at each of eight times at three different temperatures, a total of $3 \times 8 \times 10 = 240$ specimens is necessary. It is, however, convenient to expose some extra sets of ten specimens at each temperature to be able to measure at even longer times than originally planned, if the measurements indicate a longer time to failure at one or more temperatures, than foreseen at the planning of the experiment. It may also be convenient to start exposure of some extra sets of specimens at a later time in order to measure at intermediate exposure times, or at shorter exposure times than originally planned, if found appropriate during the experiment.

Since the specimens are discarded after measurement, it is not possible to follow the change in property for the individual specimens, and to determine unambiguously a time to failure for each specimen.

5.1 Times to Failure

At each test temperature the measured results are plotted on a graph of the property measured versus the time of measurement. A curve is drawn, which makes a best fit to the measured values, and the intersection of this curve with a line representing the end-point criterion determines the time to failure at that temperature, t_i.

Specifications for particular materials may call for a special treatment of the measuring results, such as plotting the logarithm of the property versus time, or some function of the property versus the

logarithm of time to obtain a simple, for instance approximately linear graph. The curve may be fitted to measured points by the method of least square. The mathematical function describing the connection between property and time depends on the type of material tested, i.e., on the order of chemical processes involved in the ageing process, and the relation between chemical composition and the property measured. Theoretical knowledge and previous experience of such processes and relations should be kept in mind when choosing the exact evaluating procedure.

5.2 Calculations

The calculations proceed essentially as described in **4**, but since only one value of time to failure is obtained from the property graph at each temperature (**5.1**), n_i becomes equal to one.

Therefore, it is not possible to determine the value s_1^2 (**4.5**), which is based on the deviation of y at fixed temperature; and the estimate s^2 of the variance of y must be based exclusively on the scatter of the values t_i about the regression line, resulting in a value of s^2 with only $k - 1$ degrees of freedom.

In order to make an estimate of the degree of conformity of the property curves, and of the linearity of the thermal endurance graph, a rough estimate of the variance s_{1i}^2 at each temperature is derived as follows.

It is assumed that the curves of property versus time for the individual specimens run parallel to the average curve of property obtained according to **5.1** — at least in the vicinity of the point where the curve crosses the end-point criterion — although only one point of each curve can be assessed, because of the destructive nature of the test.

In the property versus time graph curves are drawn parallel to the average curve, through some of the measuring points near to the cross-over point, for example, as indicated in Fig. 2, where such curves are shown through three measuring points at each of the four measuring times t_{m-2}, t_{m-1}, t_m, t_{m+1} closest to the time t_j, where the average (or best fitting) curve crosses the line representing the end-point criterion.

The intersections t_{ij} of these curves with the end-point criterion line are taken as the times to failure at the temperature θ_i, and are used in the calculation in accordance with **4.5** and **4.6**.

It is emphasized, however, that these calculations lead to rough estimates only.

5.3 The Temperature Index

When applicable, the temperature index, TI, is determined as described in **4.4**.

5.4 The Thermal Endurance Profile

The coefficient of variation, CV, is calculated in accordance with **4.9**. If $CV \leqslant 1.5\%$ the thermal endurance profile, TEP, is determined as described in **4.11**.

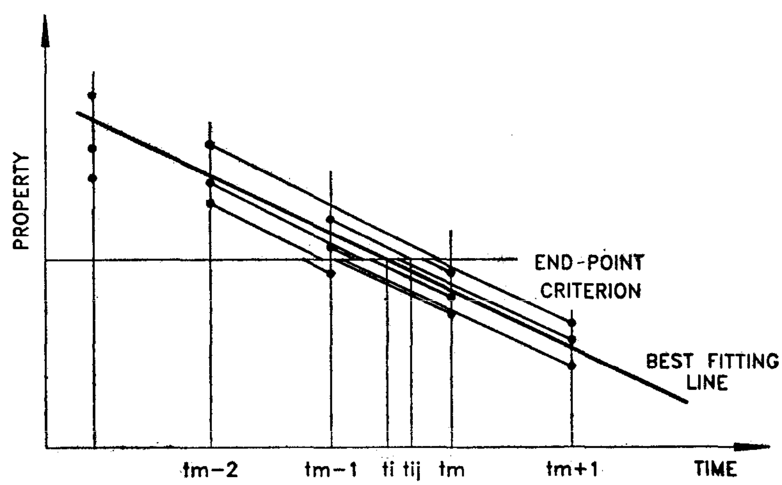

FIG. 2 DETERMINATION OF SUPPOSED TIMES TO FAILURE (DESTRUCTIVE MEASUREMENTS)

ANNEX A

0·95 Fractiles of the χ^2, t, and F Distributions

This table gives the values of $\chi^2(0\cdot95, f)$, $t(0\cdot95, f)$ and $F(0\cdot95, f_n, f_d)$, where f_n is the number of degrees of freedom of the numerator, and f_d of the denominator in the expression

$$F = \frac{s_n^2}{s_d^2}.$$

f	χ^2	t
1	3·8	6·31
2	6·0	2·92
3	7·8	2·35
4	9·5	2·13
5	11·1	2·02
6	12·6	1·94
7	14·1	1·90
8	15·5	1·86
9	16·9	1·83
10	18·3	1·81
11	19·7	1·80
12	21·0	1·78
13	22·4	1·77
14	23·7	1·76
15	25·0	1·75
16	26·3	1·75
17	27·6	1·74
18	28·9	1·73
19	30·1	1·73
20	31·4	1·73
25	37·7	1·71
30	43·8	1·70
40	55·8	1·68
50	67·5	1·68
100	124·3	1·66
500	553·2	1·65

f_d \ f_n	F				
	1	2	3	4	5
1	161	200	216	225	230
2	19	19	19	19	19
3	10·1	9·6	9·3	9·1	9·0
4	7·7	6·9	6·6	6·4	6·3
5	6·6	5·8	5·4	5·2	5·1
6	6·0	5·1	4·8	4·5	4·4
7	5·6	4·7	4·4	4·1	4·0
8	5·3	4·5	4·1	3·8	3·7
9	5·1	4·3	3·9	3·6	3·5
10	5·0	4·1	3·7	3·5	3·3
11	4·8	4·0	3·6	3·4	3·2
12	4·8	3·9	3·5	3·3	3·1
13	4·7	3·8	3·4	3·2	3·0
14	4·6	3·7	3·3	3·1	3·0
15	4·5	3·7	3·3	3·1	2·9
16	4·5	3·6	3·2	3·0	2·9
17	4·5	3·6	3·2	3·0	2·8
18	4·4	3·6	3·2	2·9	2·8
19	4·4	3·5	3·1	2·9	2·7
20	4·4	3·5	3·1	2·9	2·7
25	4·2	3·4	3·0	2·8	2·6
30	4·2	3·3	2·9	2·7	2·5
40	4·1	3·2	2·8	2·6	2·5
50	4·0	3·2	2·8	2·6	2·4
100	3·9	3·1	2·7	2·5	2·3
500	3·9	3·0	2·6	2·4	2·2

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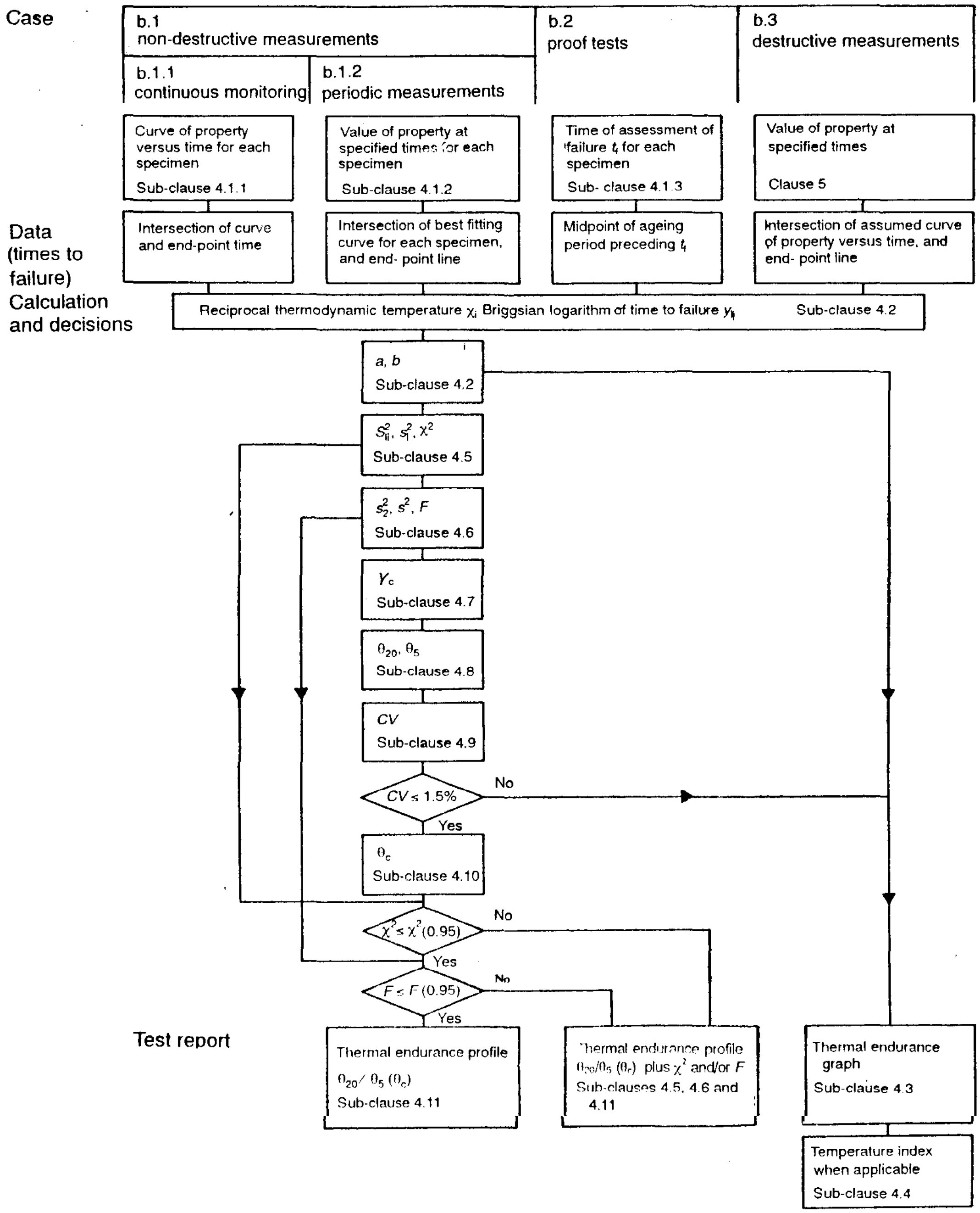
ANNEX B

FLOW DIAGRAM OF STATISTICAL PROCEDURE



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ANNEX C

LIST OF SYMBOLS

Symbol		*Sub-clause*
a	Regression coefficient	4.2
b	Regression coefficient	4.2
b_r	Intermediate constant	4.10
c	Intermediate constant	4.5
CV	Coefficient of variation	4.9
f	Number of degrees of freedom of s^2	4.6
f_d	Number of degrees of freedom of the denominator of F	4.6
f_i	Number of degrees of freedom of s_{1i}^2	4.5
f_n	Number of degrees of freedom of the numerator of F	4·6
f_1	Number of degrees of freedom of s_1^2	4.5
f_2	Number of degrees of freedom of s_2^2	4.6
F	Fisher-distributed stochastic variable	4.6
i	Order number of exposure temperature	4.1
j	Order number of specimen within sample	4.1
k	Number of exposure temperatures	4.1
n	Number of specimens exposed at one temperature	4.1
n_i	Number of specimens exposed at θ_i	4.1
N	Total number of specimens	4.1
s^2	Pooled variance	4.6
s_y^2	Variance of Y	4.7, 4.9
s_1^2	Weighted mean of s_{1i}^2	4.5
s_2^2	Variance about regression line	4.6
s_{1i}^2	Variance within set of specimens exposed at θ_i	4.5
t	Student-distributed stochastic variable	4.7, 4.10
t	Time to failure/hours	3.1
t_f	Time when failure was first observed/hours	4.1.3
t_i	Median time to failure/hours at θ_i	5.1
t_{ij}	Time to failure/hours of specimen No. j exposed at θ_i	4.1, 5.2
t_m	Measuring time/hours	5.2
x	Independent variable $1/\Theta$	3.1, 3.2
x_i	Value of x corresponding to θ_i	4.2
$\bar{x}$	Weighted mean of x_i	4.2
X	Value of x at specified value of y from regression equation	4.4, 4.7
X_c	Upper unilateral 95% confidence limit on x	4.10
X_5	Value of x corresponding to Y_5	4.8
X_{20}	Value of x corresponding to Y_{20}	4.8
y	Dependent variable, lg t	3.1, 3.2
y_{ij}	Value of y for specimen No. j exposed at θ_i	4.2
$\bar{y}$	Total mean of y_{ij}	4.2
$\bar{y}_i$	Sample mean at θ_i	4.2
Y	Value of y at specified value of x from regression equation	4.4, 4.7
Y_c	Lower unilateral 95% confidence limit on y	4.7

Symbol		*Sub-clause*
Y_i	Regression equation value of y at x_i	4.6
Y_5	Value of y corresponding to 5 kh to failure	4.8
Y_{20}	Value of y corresponding to 20 kh to failure	4.8
α	Significance level	4.5
θ	Temperature in °C	3.1
θ_c	Lower unilateral 95% confidence limit on θ_5	4.10
θ_i	Exposure temperature in °C	4.1
θ_5	Estimated temperature in °C giving 5 kh to failure	4.8
θ_{20}	Estimated temperature in °C giving 20 kh to failure	4.8
Θ	Thermodynamic temperature in kelvins	3.1
Θ_i	Exposure temperature in kelvins	4.2
σ^2	Variance (theoretical) of y	3.2
χ^2	Chi-square-distributed stochastic variable	4.5

This Indian Standard has been developed from Doc No. ETD 02 (3700).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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Printed at New India Printing Press, Khurja, India